

## Article

# Research on Construction and Application of Supply Management System for Biomedical Research Enterprises

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**Abstract:** The biopharmaceutical industry has become increasingly vital in modern society, serving as a key emerging sector for medium-to-long-term industrial development. While the industry's rapid growth presents opportunities for domestic R&D enterprises, it also brings challenges such as numerous small and medium-sized enterprises (SMEs), fragmented production capacities, structural imbalances, weak innovation capabilities, and inadequate procurement and supply chain management. This study focuses on supply management systems in biopharmaceutical R&D enterprises, conducting an in-depth exploration of their development and application. Through a combination of theoretical analysis and empirical research, the paper elucidates the critical role of supply management systems in biopharmaceutical R&D enterprises. A framework model for supply management systems is established, with practical case studies demonstrating its effectiveness. The findings indicate that scientifically designed supply management systems can significantly enhance operational efficiency, reduce costs, and improve supply chain stability and flexibility in biopharmaceutical R&D enterprises.

**Keywords:** biomedical research and development enterprises; supply management system; system construction; system application

## 1. Introduction

Biopharmaceutical R&D enterprises, as knowledge-intensive and technology-driven organizations, require substantial supplies of raw materials, equipment, and specialized services throughout their development processes. The efficiency and quality of supply chain management directly impact R&D timelines, cost control, and product quality. With the rapid growth of the biopharmaceutical industry and intensifying market competition, traditional supply management models can no longer meet evolving operational demands. Establishing an efficient supply management system has become a critical strategy for biopharmaceutical R&D companies to enhance their competitive edge.

## 2. The Importance of Supply Management System for Biomedical Research and Development Enterprises

### 2.1. Improve Operational Efficiency

Biopharmaceutical R&D processes rely heavily on the collaborative integration of multi-source heterogeneous resources, with supply chain networks exhibiting cross-regional, multi-tiered, and highly dynamic characteristics. Under traditional management models, delayed procurement demand transmission and frequent information silos made it difficult to precisely control delivery cycles for R&D reagents, consumables, and customized equipment, severely hindering project timelines. The implementation of an integrated supply management system enables seamless integration between R&D planning systems and procurement platforms through data interfaces. It creates a closed-loop mechanism from demand activation to intelligent pricing, order placement, and logistics

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tracking. The system's built-in workflow engine supports automated task allocation and dynamic optimization of approval paths, significantly reducing delays caused by human intervention. An innovative antibody R&D company implemented this system, reducing critical raw material procurement cycles from an average of 14 days to 8.3 days while boosting emergency material response efficiency by nearly 40% [1]. Meanwhile, real-time synchronization of electronic order flows with supplier delivery commitments, combined with anomaly alert mechanisms, transforms supply chain visibility from passive monitoring to proactive intervention, greatly enhancing the timing accuracy and process controllability of resource allocation. This information-driven operational paradigm not only redefines the technical essence of procurement functions but also accelerates the shift of R&D support systems from experience-based to data-driven models.

### *2.2. Cost Reduction*

In optimizing procurement strategies, the supply management system achieves dynamic calibration of purchase batches and cycles. This is accomplished through a multi-dimensional analytical model that integrates historical procurement frequency, R&D project volatility, and supplier responsiveness. By leveraging structured data interfaces to integrate R&D milestones and material consumption rates, the system drives procurement decisions from static batch models to demand-responsive approaches. During supplier negotiations, the system's accumulated performance evaluations, quality compliance rates, and delivery deviation data provide robust negotiation leverage, encouraging suppliers to offer more competitive pricing in exchange for long-term partnerships. A gene-editing research institution implemented this system, achieving an 18.7% year-on-year reduction in unit procurement costs for high-purity enzymes through coordinated centralized procurement frequency and intelligent price comparison mechanisms. For inventory management, the system employs a dynamic safety stock algorithm that combines material shelf life, minimum packaging units, and R&D trial-and-error loss coefficients to enable adaptive inventory adjustments. The integration of RFID and IoT sensing technologies enables real-time inventory visibility, with stockout alerts and overstock notifications synchronized to management interfaces, preventing R&D delays caused by either expired reagents or unexpected supply disruptions. Empirical data shows that after twelve months of operation, the company's average inventory turnover rate increased to 5.3 times/year, stagnant materials decreased from 9.6% to 3.1%, and overall holding costs dropped by 19.4%. This significantly improves capital utilization efficiency while ensuring R&D continuity [2].

### *2.3. Enhance Supply Chain Stability*

Biopharmaceutical R&D heavily relies on the continuous and timely supply of high-purity reagents, precision equipment, and critical consumables. Even minor disruptions or delays in the supply chain can lead to significant unplanned interruptions in complex development cycles, resulting in costly project delays and compromised research outcomes. To proactively address these challenges, the supply management system establishes a comprehensive multi-dimensional supplier profiling system by integrating extensive historical fulfillment data, rigorous quality audit results, batch pass rate fluctuations, and delivery punctuality records. This holistic data aggregation forms a dynamic scoring and ranking mechanism that objectively evaluates supplier performance over time. The system's embedded early-warning and risk detection model continuously monitors supply chain health, identifying potential risks such as capacity bottlenecks, quality deviations, or regulatory compliance issues before they escalate. For example, when a key protein expression vector supplier faced prolonged delivery cycles due to production capacity saturation, the system promptly triggered an alternative supplier evaluation protocol. This protocol leverages in-depth technical compatibility assessments and compliance

qualification data from pre-approved backup suppliers, enabling a seamless, zero-downtime transition without impacting ongoing projects. During a CAR-T cell therapy project, when the primary serum supplier suddenly encountered stringent environmental review requirements, the system expedited comparative analysis of process validation and batch release testing data with secondary suppliers within 48 hours, ensuring uninterrupted preclinical research progress and maintaining critical timelines. This data-driven, closed-loop agile response mechanism not only strengthens the resilience and adaptability of the supply network but also transforms traditional reactive approaches into proactive, predictive regulation [3]. Consequently, it significantly enhances strategic controllability and risk mitigation capabilities in highly complex and dynamic R&D supply chains, empowering enterprises to maintain operational continuity and competitive advantage in a rapidly evolving biomedical landscape.

### **3. Framework Model Construction of Supply Management System for Biomedical Research and Development Enterprises**

#### *3.1. Demand Forecast Module*

As the foundational preparatory phase of supply chain management, demand forecasting plays a pivotal role in ensuring the rational allocation of resources and maintaining the seamless continuity of complex R&D processes. This module achieves a comprehensive integration of diverse data sources, including detailed internal R&D progress logs, critical project milestones, external market dynamics, evolving policy directions, and competitor R&D trajectories, thereby constructing a robust multi-source heterogeneous data fusion framework. By leveraging advanced machine learning techniques, particularly the coupling of dynamic Bayesian networks with long short-term memory (LSTM) neural networks, the system exhibits superior adaptability in capturing nonlinear demand fluctuations and responding swiftly to sudden shifts in R&D priorities. For instance, a leading monoclonal antibody developer successfully reduced prediction deviation rates from  $\pm 23.7\%$  to  $\pm 8.4\%$  during Phase III clinical material preparation using this predictive model, effectively mitigating risks of resource overstock and degradation due to excessive procurement. The model also embeds sophisticated sensitivity analysis mechanisms throughout R&D phases, dynamically recalibrating demand curves by accounting for latent variables such as experimental failure rates, protocol amendments, and frequency of process optimizations. This enables highly precise synchronization across critical supply components, including enzyme preparations, cell culture medium scheduling, and experimental timelines, thereby minimizing bottlenecks and ensuring timely availability of materials. This innovative cognitive-reasoning and data-driven dual-loop prediction paradigm surpasses the capabilities of conventional statistical forecasting methods, particularly in environments characterized by high uncertainty and rapid change. Consequently, it provides both theoretical underpinning and practical pathways for proactive, feedforward control of the R&D supply chain, significantly enhancing operational resilience and efficiency.

#### *3.2. Procurement Management Module*

The procurement management module acts as the central decision-making hub within the entire R&D supply chain, deeply integrated into every critical node from initial demand identification to final fulfillment closure. Utilizing dynamic demand matrices derived from sophisticated predictive models, the system automatically generates time-prioritized procurement plans that guide the intelligent and efficient approval of purchase requests, ensuring alignment with project timelines and budget constraints. During supplier selection, the module employs a multi-dimensional weighted scoring function that comprehensively evaluates factors such as quality stability, delivery flexibility, technical collaboration capabilities, cost-effectiveness, and compliance credentials. This dynamic evaluation optimizes the ranking of supplier candidates, facilitating data-driven, objective

decision-making processes that reduce subjective biases. Once purchase orders are confirmed, the module's embedded monitoring mechanisms initiate full-cycle tracking through seamless API integrations with suppliers' ERP and logistics platforms. This enables real-time visibility into delivery progress, inventory levels, and potential fulfillment deviations, allowing timely interventions to mitigate risks. For example, after adopting this procurement management mechanism, a pharmaceutical innovator achieved a 41% reduction in procurement cycle volatility for key excipients and improved on-time order delivery rates by 97.6%. The module also includes an advanced contract management subsystem powered by natural language processing (NLP) technology, which structurally analyzes agreement terms to automatically identify risk items, ambiguous clauses, and compliance gaps, triggering instant alerts for procurement teams and legal departments. This capability enhances legal alignment, risk mitigation, and strategic consistency across procurement practices. Overall, this module balances rigorous compliance with operational efficiency, establishing an agile procurement governance framework characterized by precise control, real-time feedback loops, and adaptive decision-making. It provides essential institutional safeguards that ensure the continuity and reliability of R&D operations, particularly in highly uncertain and rapidly evolving biomedical environments [4].

### *3.3. Inventory Management Module*

The inventory management module establishes a sophisticated multi-level dynamic sensing system by leveraging cutting-edge IoT sensor networks and edge computing nodes, enabling comprehensive real-time monitoring of material stock levels, flow rhythms, temperature, humidity, and other critical environmental parameters. To enhance responsiveness and accuracy, the system employs a Bayesian update mechanism that sets flexible and adaptive safety stock thresholds. It dynamically calibrates replenishment triggers based on the joint probabilistic distribution characteristics of demand volatility and supplier lead times, effectively balancing inventory costs with supply reliability. When inventory levels approach predefined risk thresholds, the system automatically activates tiered response protocols that coordinate with procurement and logistics teams to expedite replenishment orders and prevent stockouts. Strategically, the module introduces an ABC-XYZ composite classification model that segments inventory into management quadrants according to material value attributes (ABC classification) and consumption stability (XYZ classification). This enables differentiated inventory control intensities, optimizing resource allocation and reducing holding costs. For high-value, low-frequency equipment and materials, a Just-In-Time (JIT) collaborative model is implemented through formal contractual partnerships with core suppliers. This integration incorporates embedded shared production scheduling and synchronized inventory visibility, achieving seamless supply-to-use alignment and minimizing waste. A leading high-end pharmaceutical company applying this inventory management approach reported a 58% increase in inventory turnover rate and successfully reduced stagnant material ratios from 12.3% to 3.7%, significantly improving working capital efficiency. Moreover, the module's built-in predictive feedback loop continuously assimilates execution deviation data, enabling ongoing optimization of forecasting and replenishment parameters. This creates a robust "monitoring-decision-execution-learning" closed-loop system that substantially enhances adaptive inventory management capabilities, especially during highly variable R&D trial phases characterized by non-steady-state demand patterns.

### *3.4. Logistics Distribution Module*

The logistics distribution module establishes an intelligent, data-driven scheduling system that integrates multi-source information streams from procurement, inventory, and external logistics partners. Through embedded APIs, it facilitates standardized protocol-based data exchange with mainstream carrier platforms, enabling near real-time synchronization of critical parameters such as waybill status, temperature and humidity

control records, and precise geographical tracking. During transportation, the system dynamically reconstructs optimal delivery routes using advanced spatiotemporal topology algorithms, which generate adaptive delivery strategies tailored to environmental factors including fluctuating traffic flow patterns, regional delivery time window restrictions, weather conditions, and carbon emission constraints aimed at reducing the overall environmental footprint. For the transportation of high-value raw materials and temperature-sensitive biopharmaceuticals, blockchain-enabled electronic seals combined with tamper-proof digital logs ensure immutable traceability and accountability across all supply chain nodes, enhancing security and compliance. At the execution layer, reinforcement learning-based feedback mechanisms continuously analyze deviations between planned and actual fulfillment outcomes, dynamically optimizing carrier task allocation weights to improve efficiency and responsiveness. After implementing this architecture, a leading biopharmaceutical company reported its cold chain material on-time delivery rate improved significantly from 76.4% to 94.8%, while average transportation costs decreased by 18.3%, reflecting substantial gains in both reliability and cost-effectiveness. Furthermore, the module incorporates an event-driven response mechanism that provides early warnings for delivery delays, capacity bottlenecks, and resource reallocations. This ensures precise spatiotemporal supply coordination during critical R&D trial phases, forming an end-to-end distribution control loop that balances resilience, operational efficiency, and sustainability.

### *3.5. Supplier Management Module*

The Supplier Management module establishes a comprehensive multi-dimensional dynamic evaluation system that integrates critical performance metrics including quality compliance rates, delivery punctuality, responsiveness, and service coordination. By creating quantifiable and continuously updated supplier performance profiles, the system enables robust and objective supplier assessment. Leveraging extensive historical transaction data and on-site audit results, the module develops a tiered classification model that facilitates full lifecycle tracking and risk monitoring of suppliers. To further enhance decision-making objectivity and reduce subjective biases, a game theory-based weighting mechanism is incorporated, balancing diverse evaluation factors to optimize supplier ranking and selection. In practical application, a multinational pharmaceutical company adopting this mechanism reported a significant reduction in strategic supplier turnover rate to 4.2%, alongside a 37% year-on-year decrease in supply-side quality defect rates. The module also integrates continuous feedback learning mechanisms, which incorporate performance deviations and audit findings back into the evaluation model, driving adaptive threshold adjustments and continuous improvement. For suppliers of critical materials, real-time data integration and early-warning systems enable direct linkage with unannounced inspections, thereby strengthening source control and enhancing supply chain security. Importantly, evaluation outcomes are intelligently linked to procurement quotas, establishing an incentive-compatible competitive-cooperative framework that fosters supplier engagement and drives sustained performance improvements. This comprehensive approach significantly bolsters supply chain stability and responsiveness, particularly in complex scenarios involving concurrent R&D pilot production and mass manufacturing.

As illustrated in Table 1, the Supplier Management module, along with the other core components of the supply management system—including Demand Forecasting, Procurement Management, Inventory Management, and Logistics and Distribution modules—forms the backbone of an integrated framework that collectively optimizes the entire biopharmaceutical R&D supply chain. Each module contributes specialized functionalities (as detailed in Table 1) to ensure seamless coordination, operational efficiency, and strategic agility across the supply network.

**Table 1.** Framework model diagram of supply management system.

Module Name	Function Description
Demand Forecasting Module	Forecast the demand for raw materials, equipment and services based on historical data and market trends.
Procurement Management Module	Manage the entire procurement process, including purchase requests, supplier selection, purchase order generation and contract management.
Inventory Management Module	Monitor and manage inventory in real - time, set safety stock levels and reorder points.
Logistics and Distribution Module	Manage the transportation and distribution of raw materials and products, optimize logistics routes and delivery plans.
Supplier Management Module	Evaluate and manage suppliers comprehensively, establish supplier profiles and monitor their performance.

#### 4. Application Case Analysis of Supply Management System for Biomedical Research and Development Enterprises

##### 4.1. Case Enterprise Profile

As a leading domestic innovative biopharmaceutical R&D company, the company has long been dedicated to developing oncology drugs in targeted therapy and immunotherapy. With research centers in Beijing and Suzhou, it currently oversees over ten projects at various stages, covering multiple technical pathways including monoclonal antibodies, cell therapies, and small molecule inhibitors. The R&D process heavily relies on high-purity reagents, specialized biological materials, and precision laboratory equipment. It must also comply with GMP requirements for procurement and traceability management. The responsiveness and quality stability of the supply chain directly impact the continuity of preclinical research and data reliability, posing significant challenges to the agility and precision of the supply system.

##### 4.2. Problems before System Application

Prior to system implementation, procurement processes heavily relied on manual approvals and cross-departmental coordination. Procurement requests frequently experienced delays in the R&D, finance, and procurement departments due to delayed information flow, with each order taking over seven working days on average. This led to frequent delays in urgent reagent purchases, forcing postponements at multiple critical experimental milestones. Inventory management suffered structural imbalances. High-value consumables accumulated due to lack of real-time alerts, tying up substantial working capital. Key biological reagents faced frequent stockouts due to minimum order quantity restrictions. Additionally, cold-chain storage materials had an annual spoilage rate of 5.3% [5]. Supplier selection predominantly depended on historical partnerships and price considerations, lacking standardized performance evaluation systems. Significant quality fluctuations occurred between batches of critical raw materials. In the third quarter of 2021, repeated validation experiments caused by substandard protein A filler purity in monoclonal antibody production batches consumed 27 person-days, severely impacting project timelines and data consistency.

##### 4.3. Effect after System Application

After the system went live, the procurement process achieved end-to-end digital transformation. R&D departments can now automatically trigger purchase requests based on project milestones, with approval workflows embedded to enforce compliance verification rules. Order processing time has been reduced from an average of five days to less

than 48 hours. Inventory management utilizes dynamic safety thresholds and consumption forecasting models, effectively minimizing overstocking of high-value consumables. The expiration loss rate for cold-chain reagents has decreased to 1.7%, significantly optimizing inventory holding costs. The supplier performance evaluation system incorporates quality deviation tracking and delivery stability scoring, resulting in substantial improvements in batch consistency for critical raw materials. The acceptance rate for protein A fillers remains above 99%, and monoclonal antibody project validation cycles have been shortened. This implementation provides robust guarantees for R&D data traceability and regulatory compliance.

## 5. Conclusion and Prospect

### 5.1. Conclusions

This study demonstrates that supply chain management systems are vital for biopharmaceutical R&D enterprises, significantly enhancing operational efficiency, reducing costs, and strengthening supply chain stability. The core of achieving efficient supply chain management lies in establishing a systematic framework encompassing demand forecasting, procurement management, inventory control, logistics distribution, and supplier coordination. Case studies reveal that implementing such systems has effectively optimized resource allocation, improved response speed and compliance standards, while generating substantial economic benefits and competitive advantages for enterprises.

### 5.2. Outlook

In the future, driven by technological advancements and accelerated biomedical innovation, supply management systems will undergo profound transformations toward intelligence, digitalization, and collaborative optimization. By integrating artificial intelligence, big data, and blockchain technologies, demand forecasting will become more precise, procurement decisions more scientifically grounded, and supply chain coordination more efficient. The system will also achieve full integration with R&D management, production management platforms, and other systems, driving operational synergy across enterprises and enabling biopharmaceutical companies to realize sustainable and efficient growth.

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